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Application of a Digital Elevation Model for flood modelling for the Pagsangaan River in Leyte

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Abstract

Flood related scientific and community-based data are rarely systematically collected and analysed in the Philippines. Over the last decades the Pagsangaan River Basin, Leyte, has experienced several flood events. However, documentation describing flood characteristics such as extent, duration or height of these floods are close to non-existing. To address this issue, computerized flood modelling was used to reproduce past events where there was data available for at least partial calibration and validation. The model was also used to provide scenario-based predictions based on A1B climate change assumptions for the area.

The most important input for flood modelling is a Digital Elevation Model (DEM) of the river basin. No accurate topographic maps or Light Detection And Ranging (LIDAR)-generated data are available for the Pagsangaan River. Therefore, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Map (GDEM), Version 1, was chosen as the DEM. Although the horizontal spatial resolution of 30 m is rather desirable, it contains substantial vertical errors. These were identified, different correction methods were tested and the resulting DEM was used for flood modelling.

The above mentioned data were combined with cross-sections at various strategic locations of the river network, meteorological records, river water level, and current velocity to develop the 1D-2D flood model. SOBEK was used as modelling software to create different rainfall scenarios, including historic flooding events. Due to the lack of scientific data for the verification of the model quality, interviews with local stakeholders served as the gauge to judge the quality of the generated flood maps. According to interviewees, the model reflects reality more accurately than previously available flood maps.

The resulting flood maps are now used by the operations centre of a local flood early warning system for warnings and evacuation alerts. Furthermore these maps can serve as a basis to identify flood hazard areas for spatial land use planning purposes.

Keywords: digital elevation model, correction methods, river flood model, ASTER GDEM

Introduction

The Pagsangaan River in Leyte and its tributaries constitute the main river system in Ormoc City and the municipalities of Kanaga, Villaba, and Matag-ob in Leyte. Settlements adjacent to the river are especially vulnerable to flood events, caused by heavy rainfall occurring most commonly due to typhoons. In recent years, the precipitation caused by typhoon Milenyo (2006) and Typhoon Frank (2008) exceeded the capacity of the Pagsangaan River resulting in extensive flooding, and substantial losses and damages to the local communities. In order to prevent or reduce losses of life and livelihood, as well as damages to property, crops and infrastructures, the Government of Ormoc City has implemented various initiatives for disaster risk reduction (e.g. establishment of a local flood early warning system).

Currently, all existing flood hazard maps for the area are highly inaccurate, contradictory, and fail to reflect several known flood prone areas. Furthermore, they do not assess the possible effects of climate change or levels of rainfall intensity, thus, making it impossible to create realistic evacuation plans for different levels of emergency. In contrast, computer generated flood models are able to provide detailed information on the spatial and temporal extent of floods responding to different meteorological inputs including rainfall intensity.

Flood models need a wide range of data as input, where one of the most important elements is the Digital Elevation Model (DEM) of the basin because it determines the gravity-driven flow of water downhill towards the sea. The DEM used for the present project was obtained from the Advanced Thermal Emission and Reflection Radiometer (ASTER).

The only locally generated elevation data, a topographic map 1:50,000 based on aerial photographs of 1947-53 with altitude steps of 5 m in the low lying areas [1], was not sufficiently accurate for flood modelling. Therefore, a DEM generated by the ASTER sensor with a horizontal resolution of 30m by 30m pixels and 1 m vertical resolution was chosen. At the time of the research only the first version of the ASTER-DEM had been published. This version contained a significant number of structures suspected to be artefacts. Consequently, the DEM had to be physically verified and corrected.

A computer based flood model would allow the study of different scenarios to develop an array of hazard maps that could be related to field rainfall and water depth gauging stations. Thus, creating tailored evacuation and warning plans that would in turn save lives and economic assets. Moreover, this process has the added benefit of giving the various local authorities further insight into models for integrating the flood hazard classifications with the land use plans and target mitigation measures more effectively.

Data collected and methods used

The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) jointly released the ASTER Global Digital Elevation Model (GDEM) in June 2009 and in October 2011 Version 2 [2]. The ASTER data consists of two files: the final GDEM and the Quality Assessment (QA) file. The GDEM was gained by removing clouds out of several single DEMs, stacking those cloud-screened single DEMs, removing residual outliers and calculating the GDEM's final pixel value by averaging all available values of the stacked single DEMs. In case no ASTER data were available Shuttle Radar Topography Mission (SRTM) were used as substitutes. The QA file contains information on the source of each pixel value.

Unexpected DEM morphology appears at the boundaries between different stack number areas in the QA file. Due to the algorithm used for the calculation of the final ASTER GDEM pixel value long, dam-like barriers ("mole runs") ranging between three meters up to 100 meters height difference occur in the final GDEM, but also pits and bumps. In order to evaluate the structures suspected to be artefacts in the DEM of the watershed, 63 locations were surveyed in a range of 500 m, 57 in a range of 300 m and 41 at the exact location.

Overall, out of a total of 94 suspected structures, only 71 locations were examined due to time and resources constrains. They were all found to be artefacts and corrected using systematic correction methods.

To address this issue, the ASTER-GDEM elevation values were compared to the DEM from the SRTM Version 2. The comparison of the two elevation models was done by calculating the SRTM pixel values minus the ASTER pixel values (in a horizontal resolution of approximately 30 m) and revealed a vertical deviation by a mean of 9.226 m. Therefore, the SRTM DEM was shifted downwards by 9.226 m.

The correction threshold was determined to be 20 m difference between ASTER and SRTM. All values above this threshold were substituted in the ASTER-GDEM by using the Inverse Distance Weighted Technique (IDWT), and a search radius of twelve points for interpolation. As areas below 100m above sea level were observed to be very flat or only gently sloping in the Pagsangaan watershed, additional points within 60m around the identified artefacts were eliminated to avoid remaining artefacts of just under the 20m threshold and therefore to achieve smoother results. This extended modification of the GDEM was not applied to the regions above 100m as it would have resulted in a high loss of information in areas with a more hilly character and steeper slopes.

Artificial barriers ("mole runs") were corrected by comparing the GDEM to the QA file. It was found that particularly long boundaries in the QA file affect the GDEM. To isolate these boundaries, the QA file was converted to a set of polygons in order to calculate the area and later to point data files to substitute all points lying in areas smaller than 15,000 square metres (approximately three by five ASTER QA file pixels or less) by the surrounding values to produce a simplified QA file.

The point data files were converted back to polygons and buffer zones were added to the boundaries. The buffers were defined as 45 m to each side of the boundary (90 m in total or three ASTER GDEM pixels). This data set was subjected to the abovementioned correction procedure and the resulting point data file was finally converted to a raster DEM with the same resolution of 30m pixel size as the original DEM, which has exactly the same resolution, position and pixel values as the original DEM, except for the corrected values. It served as the basis for flood modelling.

Several flood modelling software packages were studied based on the following criteria: robustness of the numerical scheme, user friendliness, and type of output, cost, and existence of a support community. SOBEK developed by Deltares (previously WL|Delft Hydraulics) was selected. The coupled system 1D channel network/2D overland flow module was designed for simulating overland flooding [3]. ArcGIS 9.3 (including the hydrology and drainage enforcement tools) was used for data geo-processing.

Various sources of meteorological data were utilized from the National Irrigation Agency (NIA), the Local Government Units (LGU) of Kananga and Ormoc and from the Tropical Rainfall Monitoring Mission [4]. The Department of Public Works and Highways (DPWH), Material Quality Control and Hydrology Division provided some of the river cross-sections, and further measurements were carried out using a Total Station laser scanner and a Global Positioning System (GPS) device. River discharge records were obtained from DPWH for the regularly monitored rivers and further measurements were also carried out by the work team for the remaining tributaries. The hydraulic resistance was derived from a land cover map developed in 2009 from images taken from ASTER and SPOT5. The classification was supervised by the University of the Philippines [5].

A Soil Map of Leyte based on the local classification from 1947 was obtained from the Bureau of Soil and Water Management (BSWM). Tidal data were obtained from the National Mapping and Resources Information Authority (NAMRIA). The A1B projections from the Intergovernmental Panel on Climate Change (IPCC) [6] predict a rainfall increase for the Visayas region of 1 to 16% by 2050 [7]. The authors evaluated the worst case scenario under A1B simulating a 16% increase.

The model included: 6 boundary nodes (5 at the upper boundaries and 1 at the estuary) and a 5 minute time step.

Results

The comparison between ASTER-GDEM Version 1 and the output from the first applied correction method showed a reduction in pits and bumps as illustrated in Fig. 1.

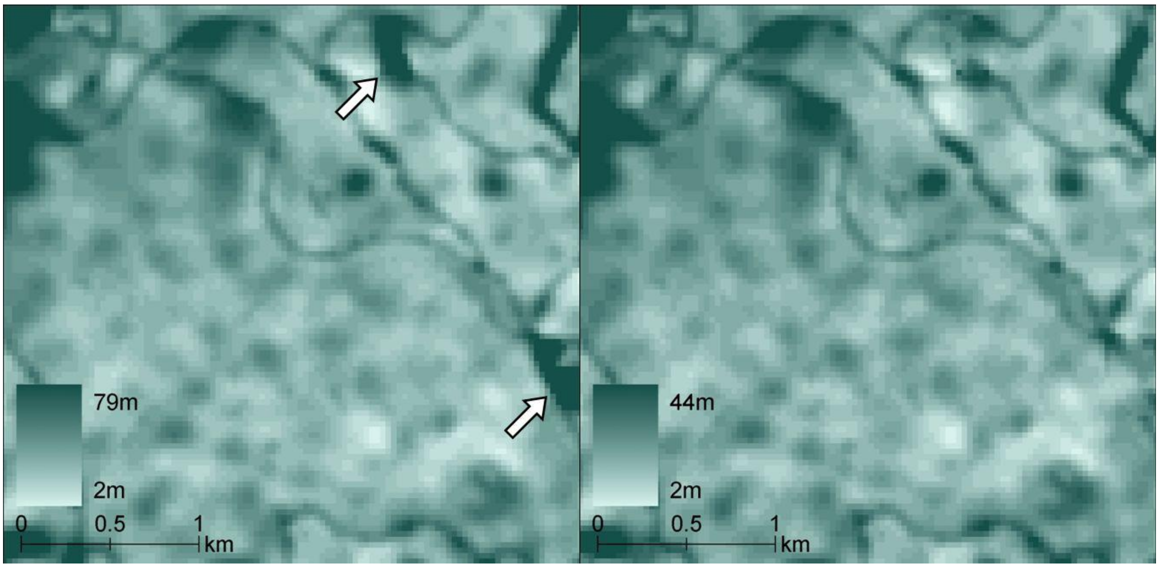

Figure 1: Example of automatic corrections of bumps of ASTER-GDEM. The original is displayed on the left, the corrected version on the right. Arrows point to corrected areas. Due to the changing value ranges, the colour schemes are slightly different.

The output from the first correction method was used to correct the "mole runs". As can be observed in Fig. 2 a significant reduction of these artefacts was achieved. However, it was also found that a small number of artefacts remained.

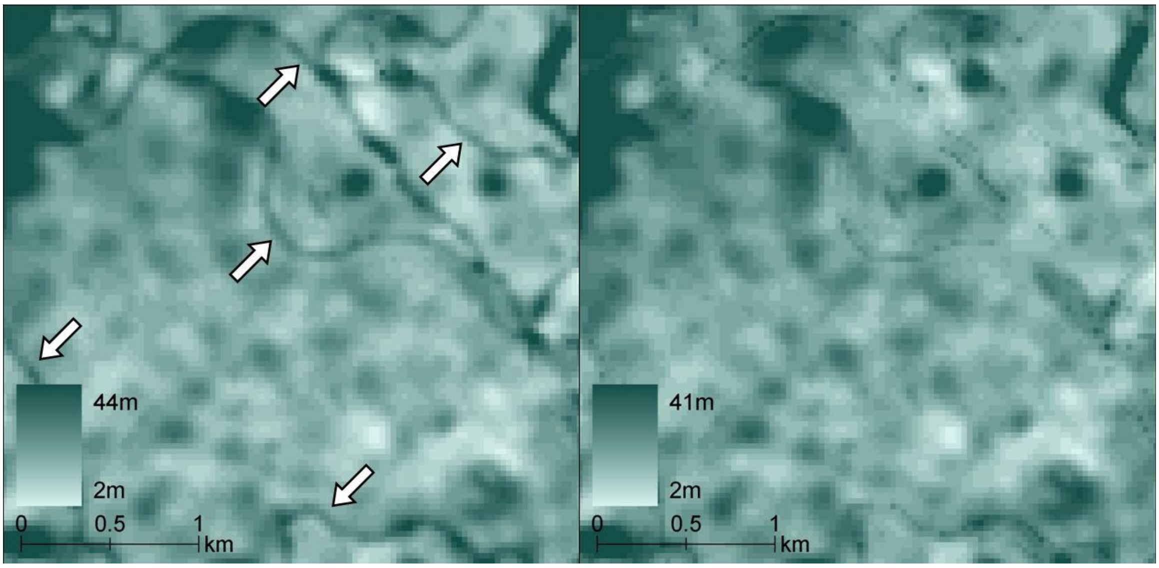

Figure 2: Example of the automatic correction of artificial barriers of the ASTER-GDEM. Left: result of bumps/pit correction, right: with additional barrier correction. Arrows point to samples of corrected areas. Due to the changing value ranges, the colour schemes are slightly different.

The corrected raster was compared to the ASTER-GDEM version 2, released in 2011, where the number of artificial barriers is significantly reduced although several pits and bumps are still visible [Fig. 3].

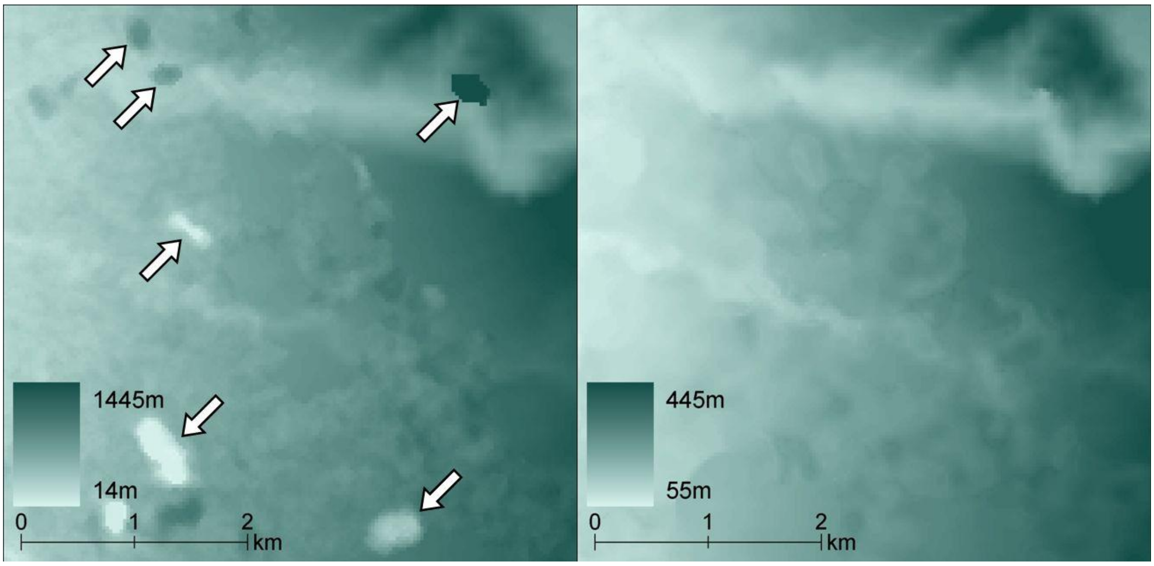

Figure 3: Example of the automatic correction of ASTER-GDEM Version 1 by the authors (right) with Version 2 of ASTER-GDEM (left). As it can be observed, although Version 2 still contains artefacts, the version produced by the authors does not. Colour schemes are slightly different.

After the previously mentioned correction method, the corrected DEM still exhibited 2,457 sinks. Therefore, ArcGIS tools were used to identify and fill those sinks.
Typhoon Frank (international name Fengshen, 20-22 June 2008) was simulated using available data from the NIA rainfall records for the duration of the tropical storm. The simulation outputs at the largest flood extent were compared to community-based maps [8] and the flood hazard (susceptibility) map produced by the Mines and Geoscience Bureau (MGB)[9][Fig. 4].

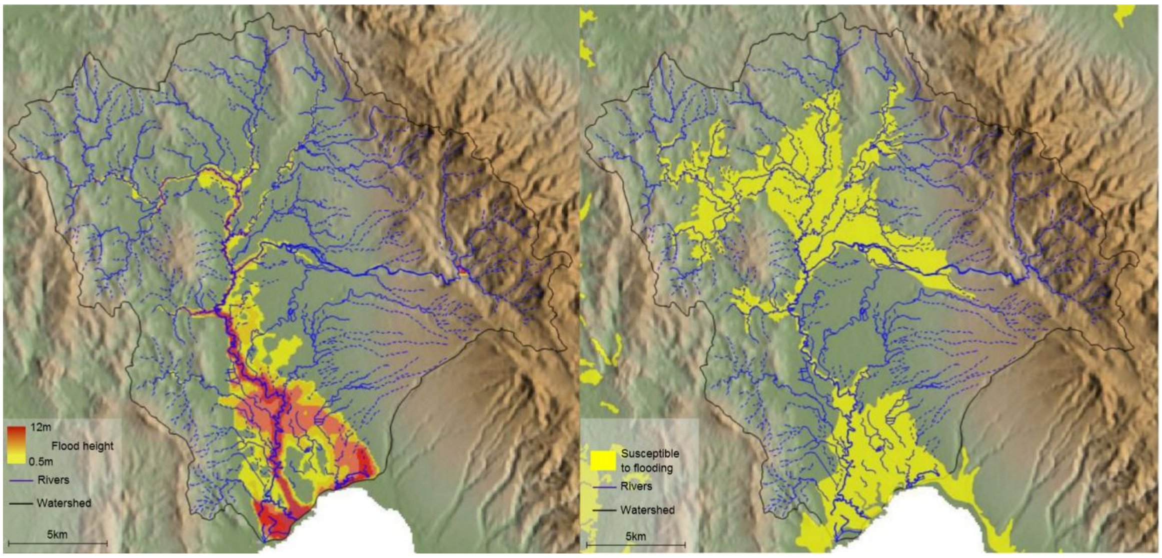

Figure 4. Comparison of GIZ model calculations (left) and hazard areas as identified by MGB (right) for 525mm/24h in the model and maximum flood extent from MGB.

Assumptions from climate change models were used as a basis for simulating a similar event to Typhoon Frank adding higher rainfall and sea level rise. The result showed a significantly increased flooded area [Fig. 5].

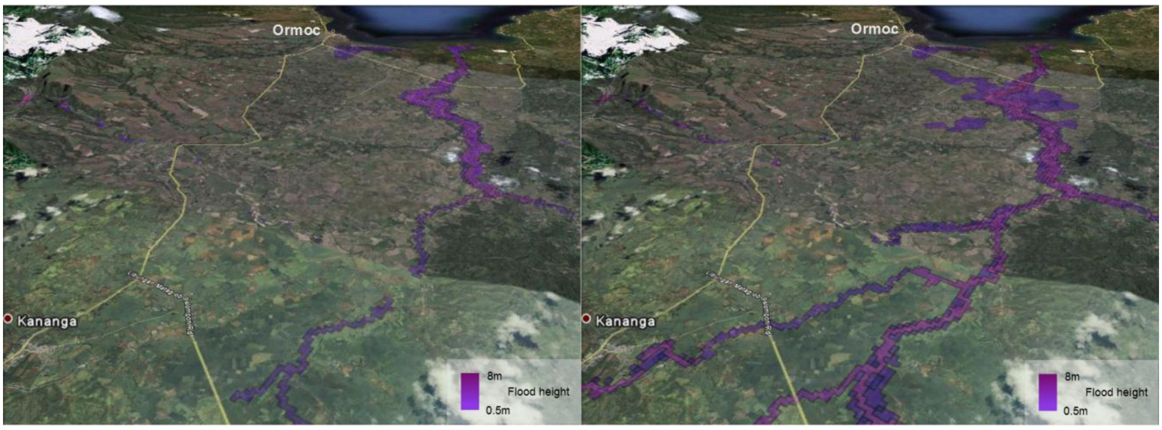

Figure 5. Simulation of the rainfall during Typhoon Frank 251.7 mm in 3 days (situation on 21.06.2008; left) vs. 16% precipitation increase and sea level rise (292 mm in 3 days, 22 cm Sea Level Rise, 2050s, right). The flooded areas are shown in purple/blue on Google Earth imagery. The distance between Kananga and Ormoc is approximately 20km.

Further simulations were carried out to reproduce historic events as well as the following scenarios: 100 mm, 200 mm, 300 mm, 400 mm, and 525 mm in 12 hours. These scenarios were converted to maps in 4h steps and made available to the Local Government Units of Kananga and Ormoc.

Discussion

The corrections applied by the authors of the ASTER-GDEM Version 1 appear to be more thorough than those included in the Version 2 of ASTER-GDEM, which still exhibits a considerable number of artefacts (mostly pits and bumps). Therefore, the DEM produced by the work team is the most accurate data set currently available for the Pagsangaan river basin. However, the vertical error of this DEM is still far from the desired 10 cm accuracy. Further corrections (sink filling, drainage enforcement) were necessary to acquire a DEM appropriate for flood modelling purposes. Almost all corrections were carried out using standard tools and should be verified through ground surveys and adjusted if necessary.

In the absence of sufficient rain and river level data it was not possible to perform a thorough calibration of the model. Therefore, the model was partially calibrated and validated using community-based flood maps. It was generally agreed that the flood model output reflects reality more accurately than the previously available flood hazard maps. Furthermore, the temporal resolution and the indication of flood depths added valuable information for local decision makers.

The results of the simulations have been shared with the project Nationwide Operational Assessment of Hazards (NOAH) of the Department of Science and Technology. The operation centre of the Pagsangaan Flood Early Warning System in Ormoc was provided with a set of maps for different rain scenarios and can determine evacuations strategies accordingly. Furthermore, the data may serve as a basis for improved land use planning by allowing local governments to identify potential future flood prone areas.

However, the complexity and cost of the software package constitutes a significant limitation to further local applications. In addition, the long calculation time hinder the potential use as

a dynamic tool for real-time events. Different software or more up to date hardware may be a solution to this issue.
Further efforts in cooperation with the University of the Philippines, National Institute for Geological Sciences and the University of Potsdam, Germany, will be carried out to calibrate Doppler radar data generated by a station in Mactan, Cebu, using meteorological field measurements in the Pagsangaan watershed. Such data might be used in the future for further simulations and improving the quality of the model.

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